Development of a Quasi-2D Sediment Transport Model in Coastal Area

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論 文 内 容 要 旨

1. Introduction

Several methods have been proposed by researches to evaluate coastal sediment transport in coastal area. Field data has been collected to study the behavior of erosion and offshore migration of sand bar influenced by cross-shore suspended sediment flux due to an offshore directed mean current. The difficulty of this method is that we cannot control the parameters addressed in a particular phenomenon. Numerical model is more preferable for this kind of issues. Three-dimensional (3D) hydrodynamics model has been applied to simulate wave current and sediment transport as well. However, this model is time consuming to be applied in wider range of coastal area. Quasi-3D model is the most preferable which solve for the vertical variation of the currents and included the leading order effect of the depth-varying currents on the depth averaged flow filed all on a two-dimensional grid. The aim of this study is to develop a good model of sediment transport for the assessment of morphological change in coastal area. As the first stage of the quasi-3D model development, quasi-2D model has been developed. Prediction of wave conditions and wave-induced currents in the surf zone has been improved. Artificial viscosity on breaking term of Boussinesq-type wave model has been developed relating with eddy viscosity. This eddy viscosity is useful to evaluate wave decay, vertical distribution of suspended sediment concentration and longshore current as well.

2. Literature Review

Extensive development of numerical models on morphological evolution around coastal area has encompassed significant improvements through the years. However, the morphological bed level change processes are extremely complex and some are beyond our current state of knowledge. Some models have their own advantages and limitations. Combination of the advantages between these models will give a better new model to evaluate sediment transport.

At present, some models have been developed by researchers to simulate sediment transport under wave condition. However, careful estimation on suspended load transport is still very poor. For example, coupling between MPM and Bagnold-type sediment transport model cannot produce expected erosion in surf zone, because both of models only predict bed load transport. Bagnold-type simulated better erosion in surf zone than MPM model, however, bed level change near the breaking point was underestimated. In this study, by considering the effectiveness of Bagnold-type model in surf zone, a coupling between this model and suspended load transport has been proposed. Proposed model of suspended sediment transport was developed by considering vertical distribution of both water particle velocity and sediment concentration.

3. Quasi-2D Mathematical Modelling of Wave Propagation

We demonstrate the capability of a numerical model called Funwave1D, for the study of wave propagation in surf zone. Surf zone hydrodynamics on laboratory with uniform bottom slope, subject to regular wave condition, is quantitatively simulated by the numerical model. The model used governing equation based on Boussinesq-type equations to simulate wave propagation from deep to shallow water. The governing equations solve wave properties in horizontal space, while the vertical profile of water particle velocity were approached by using polynomial equation. The governing equations are solved by Finite Difference Method using 3rd order Adams-Bashfort explicit predictor and 4th order Adams-Moluton implicit corrector for time integration and 4th order difference scheme for spatial discretization. Staggered grid system was employed to improve the numerical stability.

Three kinds of boundary conditions were set in the computation domain. Incident wave boundary was applied by using a source function to generate desire wave height. Solid boundary condition was applied in the boundary between wet and dry points. Absorbing boundary was applied by using artificial damping terms like a sponge layer in the offshore end of computation domain to absorb wave energy. The existing wave source function was calibrated to accurately generate desire wave height during the simulation. Some available laboratory data of wave height ranging from spilling to plunging breaker wave condition were used for the calibration. Calibration coefficient was added in the source function to adjust the generate wave height. This value was obtained by using trial and error process for each case of laboratory data. Surf similarity is used to define the type of wave breaking. The result shows that the higher the surf similarity is the higher the calibration coefficient.

4. Eddy Viscosity Model

New eddy viscosity model has been proposed by improving the definition of existing artificial viscosity model developed by Kennedy. In Kennedy model, eddy viscosity was only determined by vertical velocity of water surface fluctuation. Since horizontal velocity is higher than vertical velocity in a period of wave propagation, it has been included in the proposed eddy viscosity model. Two length scale of local depth water and depth water at breaking point accordingly to incorporate the selection of dominant factor between horizontal and vertical velocity in determining the eddy viscosity. By using these two length scale, the eddy viscosity near the breaking point was mainly determined by vertical velocity while horizontal velocity when the wave closer to the shoreline. Since wave breaking affect both of wave decay and sediment concentration, the relationship between artificial viscosity and eddy viscosity has been proposed in this study. This relationship was derived from Reynolds equations of turbulence flow.

Proposed eddy viscosity was calibrated against Full-2D model data under the conditions of plunging and spilling breaking wave case. Proposed model produced underestimation of eddy viscosity in surf zone specifically for spilling breaker case. Discrepancies between the model results at the measured breaking point and the experiment data were attributed mainly because the model is a weakly nonlinear. Evaluation of wave decay, surface elevation and wave-induced current has been conducted against laboratory data. Small eddy viscosity produces a deviation of wave height compared to laboratory data in surf zone. The simulations with developed eddy viscosity model indicated that Kennedy's model obtained better simulation than proposed model. Near the shoreline both plunging and spilling breaker case was also underestimated in eddy viscosity. However, the advantage of using this model is that more challenging for the simulation of suspended sediment distribution.

5. Sediment Transport Model

Developed eddy viscosity model has been applied in the quasi-2D model to simulate vertical distribution of sediment concentration. Experimental data of sediment transport in a wave flume was used to validate the model in terms of sediment suspended sediment concentration and morphological change. It has been discussed in the previous paragraph that proposed model of eddy viscosity produce higher discrepancy of velocity profile when the wave approaches the shoreline. Since sediment concentration in this area is not high compare to that of near the breaking point, the effect of the discrepancy is not significant in sediment transport. Even though proposed model calculated lower sediment concentration profile than measured data in surf zone, but it accurate to predict of that near the breaking point where much higher sediment concentration has been observed.

Coupling between Bagnold-type sediment transport and suspended load transport indicated that both bedload and suspended load has its own dominancy in coastal area. Bedload transport is dominant in surf zone, erodes sediment to seaward direction. Turbulence due to wave breaking makes suspended load transport dominant near the breaking point, erodes sediment to onshore direction. Morphological change by using sediment settling/pick-up rate produces better result than morphological change due to total load sediment transport even though the deviation is not significant. Unexpected erosion in swash zone is occurred because of the infiltration-exfiltration in laboratory during the run up process has not been considered in this model. The infiltration-exfiltration makes the settling velocity higher producing accretion in swash zone as shown from laboratory data. If the model can predict accretion in swash zone well, more erosion in surf zone can be expected.

6. Model Application

The developed eddy viscosity model was further applied to quasi-3D model to simulate wave decay as well as longshore current in two horizontal dimension of coastal area. Laboratory experiment data conducted in a Large-scale Sediment Transport Facility (LSTF) at U.S. Army Engineer Research and Development Center's Coastal and Hydraulics Laboratory was used to validate the model. Underestimation of longshore current produced by this model was caused by the underestimated of velocity profile in surf zone.

7. Conclusions and Recommendations

Relationship between eddy viscosity and artificial viscosity has been proposed which has a significant importance for the simulation of wave decay and suspended sediment transport as well. Coupling between suspended load transport and Bagnold-type model gives accurate bed level change near the breaking point. Further development in terms of velocity profile due to wave breaking is required. The simulation of morphological change can be achieved by considering the inclusion of infiltration/exfiltration processes in swash zone. Moreover, bed load and suspended load efficiency are needed to be evaluated during the uprush and backwash processes.

論文審査結果の要旨

海岸侵食の克服は、我が国はもとより世界各国で顕在化している国土保全上の重要課題である。この現象を予測する技術が強く求められているが、現象は広域で、長期におよび、しかも３次元的であるために、予測計算には膨大な演算時間を有するという課題がある。本研究は、準２次元土砂輸送モデルの開発を目的とし、計算時間の短縮と予測精度の確保を目指し、ついで準３次元問題に拡張して、上記課題に応えようとするものである。

第１章は、序論であり研究背景と目的を述べている。

第２章は、文献調査であり、既往の研究を調査し問題点を総括している。土砂輸送が最も活発な砕波帯において、波高の減衰と、浮遊砂の巻き上げの２つの現象が何れも渦動粘性と関連するが、従来異なる粘性係数が用いられており、これを統一する必要があることを明らかにした。これは、本研究を進める上で重要な整理である。

第３章は、Boussinesq 方程式を解くための、数値解析技術の展開について述べている。準２次元近似では、流れの鉛直分布を２次関数で近似しているが、所要の精度を確保するための工夫について説明している。

第４章は、渦動粘性モデルについて述べている。砕波帯における波高減衰を評価する人工粘性と浮遊砂の巻き上げを表す渦動粘性を関連付け、２つの現象が統一的にモデル化されることを示した。これは、砕波帯の土砂輸送を評価する重要な進展である。

第５章は、土砂輸送モデルについて述べている。与えられた渦動粘性係数に対して、土砂の沈降と巻き上げが平衡する仮定を設け、浮遊砂濃度の鉛直分布を近似する準２次元モデルを提案し、浮遊砂の輸送や海底地形の再現性など評価精度が高いことを示した。これにより、流れと土砂輸送の両方の計算において準２次元モデルが整備されることになり、画期的な技術開発である。

第６章は、準３次元問題への拡張について述べている。平面的な地形を有する海岸に波が斜め入射した場合の沿岸流の分布を計算した。水理実験結果に比べ過小評価になっているが、分布形は再現されており、段波形成時における準３次元モデルで運動量フラックスが過小評価になっていることが主要因であることを明らかにした。これは、現地適用性を高めていく上で重要な知見である。

以上のように、本研究は、沿岸域における土砂輸送の準２次元、準３次元モデルを開発し、海岸工学の進展に大きく貢献したものである。

よって、本論文は博士(工学)の学位論文として合格と認める。